A framework for the analysis of problem-based learning methods is presented, using concepts from cognitive psychology.

Connecting Problem-Based Practices with Educational Theory

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Problem-based learning (PBL) derives from the theory that learning is a process in which the learner actively constructs knowledge. Modern cognitive psychology suggests that learning results from a learner’s actions and that instruction plays a role only to the extent that it enables and fosters constructive activities (Bereiter and Scardamalia, 1992). Transmission of subject-matter through direct instruction (lecturing, for example) is, from this perspective, only of limited use. If instruction is to play any role in the learning process, teachers should focus on helping students acquire self-directed learning skills.

Problem-based learning is regarded as an approach that meets this requirement (Schmidt, 1993). Problems serve as the stimulus for learning. Students encounter problem-solving situations in small groups that are guided by a tutor, whose role it is to facilitate the learning process by asking questions and monitoring the problem-solving process. This is quite different from most university teaching practices, which concentrate on the transmission of factual knowledge. PBL employs different instructional conditions to result in effective student learning (Norman and Schmidt, 1992). To create or improve PBL curricula, it is important to understand what kind of instructional conditions result in effective problem-based learning. This issue may be clarified by examining how the PBL method is grounded in current theories of learning and instruction and then by applying insights from these theories to refine the practice of problem-based learning.

The first section of this chapter describes certain fundamental principles of learning and instruction that are relevant to problem-based learning. The second section provides examples from the PBL process to illustrate how fundamental principles of cognition relate to instructional design in problem-
based learning. The final section looks at opportunities to improve the effects
of problem-based learning on student learning.

Current Theories of Learning and Instruction

Findings from cognitive psychology provide a theoretical basis for improving
instruction in general and problem-based learning in particular. A basic
premise in cognitive psychology is that learning is a process of constructing
new knowledge on the basis of current knowledge. According to Glaser
(1991), it is generally assumed that learning is a constructive and not a recep-
tive process, that cognitive processes called metacognition affect the use of
knowledge, and that social and contextual factors influence learning.

**Principle 1: Learning Is a Constructive and Not a Receptive Process.**

Until twenty or thirty years ago, education was dominated by the view that
learning involves filling students' heads with information (Brue, 1993).
Human minds were regarded as empty buckets that could be filled through
repetition and rehearsal. Accordingly, teaching led directly to students' storing
knowledge in memory, like books are stored in libraries. Retrieving informa-
tion depended on the quality of the call numbers used by students in classify-
ing the information. However, modern cognitive psychology tells us that one
of the most important features of memory is its associative structure (Brue,
1993; Bruning, Schraw, and Ronning, 1995). Knowledge is structured in
networks of related concepts, referred to as semantic networks. As learning occurs,
new information is coupled to existing networks. Depending on how this is
done by learners, new information may be effortlessly retrieved and used to
solve problems, recognize situations, or recall factual knowledge.

Semantic networks are not only a way of storing information; they also
influence how information is interpreted and recalled. For example, while
reading a new text, certain passages will activate networks that contain exist-
ing knowledge needed to construct and retain the new text's meaning. If this
does not occur, reading comprehension is inhibited. The following example
illustrates this point. Read the passage once, then close the book, and write
down as much as you can remember.

The procedure is actually quite simple. First you arrange things into different
groups. Of course, one pile may be sufficient depending on how much there is
to do. If you have to go somewhere else, due to lack of facilities, that is the next
step, otherwise you are pretty well set. It is important not to overdo things. That
is, it is better to do a few things at once than too many [Brue, 1993, p. 181;
example adopted from Bransford and Johnson, 1972]

Brue asserts that although the text in the example is quite simple, it is apt
to be poorly understood. Most people read the passage slowly and focus for a
long time on certain text parts. This process is generally regarded as seeking
existing semantic networks that could interact with information in the text to
construct meaning. If the title of this passage, "Washing Clothes," had been given first, the text would have been read rapidly and easily remembered. The title "Washing Clothes" activates existing knowledge related to information in the text. Consequently, in education, explicit attention should be paid to students' existing knowledge and the activation of this knowledge to provide a framework for learning. Activating existing knowledge to facilitate processing of new information is regarded as a basic requirement of learning.

**Principle 2: Knowing About Knowing (or Metacognition) Affects Learning.** A second important principle is that learning is quicker when students possess self-monitoring skills generally referred to as metacognition (Brue, 1993). Metacognition is viewed as an essential element of skilled learning; goal-setting (What am I going to do?), strategy selection (How am I doing it?), and goal evaluation (Did it work?). Successful problem solving is not only dependent on the possession of an extensive body of knowledge, but also on the use of problem-solving methods to accomplish goals. According to Glaser (1991), several studies have shown that good students monitor their comprehension failures and successes while studying textbooks. Good students detect when they do—or do not—understand text and know when to use alternative strategies to understand learning materials. Typically, metacognitive skills include the ability to monitor one's own learning behavior, that is, being aware of how problems are analyzed and whether problem-solving results make sense. Studies of expert performance have shown that experts, in contrast with novices, constantly judge the difficulty of problems and assess their progress in resolving them (Glaser, 1991).

Some evidence exists that metacognition has to be developed in education, because monitoring of the learning process is usually late in developing (Bruning, Schraw, and Ronning, 1995). Fortunately many of these skills are teachable. Bruning, Schraw, and Ronning discuss several teaching strategies that can be used to teach metacognition: encourage students to engage in deep processing, focusing on understanding rather than surface memory; promote elaboration of new ideas; and help students become more metacognitively aware by demonstrating the kinds of questions they can ask themselves during problem-solving action.

**Principle 3: Social and Contextual Factors Influence Learning.** The third principle is about use of knowledge. Leading students to understand knowledge and to be able to use problem-solving processes are ambitious goals in higher education. Instruction typically begins by exposing students to disciplinary knowledge, and then assigning a series of end-of-chapter problems to promote the use of that knowledge.

Unfortunately, studies have shown that students experience serious difficulties in using scientific knowledge (Bruning, Schraw, and Ronning, 1995). Students also have erroneous beliefs about major principles in scientific disciplines. For example, studies have shown that traditional education does not facilitate an enhanced understanding of physics problems despite formally taught physics theories (for example, Clement, 1983). Similar results were
found in economics education (Boshuizen, 1995). Indeed, research by Mandl, Gruber, and Renkl (1993) showed that psychology graduate students outperformed economics graduate students in a business simulation game. Graduate students in economics had the knowledge, but were unable to use it in a context that required fast and frequent decision making. On the other hand, psychology students had little knowledge of economics, but developed during the game a simple, partially incorrect, but effective decision-making model. Graduate students in economics used a complex model, but were unable to apply it during fast-paced problem-solving action. Mandl, Gruber, and Renkl (1993) found similar results with students in medicine. Medical students did not sufficiently relate signs and symptoms with the diagnoses formulated, ignored information that did not fit into their primary diagnosis, and were incapable of restructuring and synthesizing information presented in the case. According to Boshuizen (1995), numerous studies indicate that problems regarding the use of knowledge pervade higher education.

If our goal is to teach students to use their knowledge to solve real-world problems, then how should teaching occur? Mandl, Gruber, and Renkl (1993) propose a fourfold strategy to make university teaching more effective and resolve the problem of inert knowledge: instruction should be placed in the context of complex and meaningful problem-solving situations; instruction should focus on teaching metacognitive skills and when to use them; knowledge and skills should be taught from different perspectives and applied in many different situations; and instruction should take place in collaborative learning situations so as to confront students with beliefs held by other students. This strategy is based on two complementary models of contextualized learning: cognitive apprenticeship (Collins, Brown, and Newman, 1989) and anchored instruction (Bransford and others, 1990). Both models emphasize that teaching should take place in the context of real-world problems or professional practice (Williams, 1992). Cognitive apprenticeship emphasizes learning in the context in which students will perform when graduated. The major goal of apprentice learning is for students to see how experts use subject knowledge and metacognitive skills on a problem. Students need opportunities to see how experts analyze problems, to get feedback on their own actions, and to get suggestions during the process. In anchored instruction, students study concepts over an extended period of time in a variety of contexts. Through linking of content with context, knowledge becomes more accessible when confronting new problems (Schmidt, 1993).

Social factors also influence individual learning. Glaser (1991) argues that in small group work, the learner's exposure to alternative points of view is a real challenge to initial understanding. In small group work, students evoke their problem-solving methods and conceptual knowledge. They express their ideas and share responsibility in managing problem situations. Different views on a problem are observed, leading students to ask new questions. Bruning, Schraw, and Ronning (1995) argue that science instruction is more effective
when the social nature of learning is recognized and used to help students acquire accurate scientific understanding.

Principles of Learning as Applied in Problem-Based Learning

Problem-based learning typically involves students working on problems in small groups of five to twelve with the assistance of a faculty tutor. Problems serve as the context for new learning. Their analysis and resolution result in the acquisition of knowledge and problem-solving skills. Problems are encountered before all relevant knowledge has been acquired and not only after reading texts or hearing lectures about the subject matter underlying a problem. This latter feature reflects one of the essential distinctions between problem-based learning and other problem-oriented methods (Albanese and Mitchell, 1993).

The problem-based tutor’s function is to coach the group by providing support to make student interaction productive and to help students identify knowledge needed to resolve the problem. As a result of the problem-solving process, students generate questions (learning issues) about what kind of knowledge is required to explain the mechanisms underlying the causes of the problem. After leaving the meeting, students do research on the learning issues using a variety of resources. Significant time is available for independent study. The PBL process is completed when students report in the next meeting about what they have learned. The students’ first goal is to relate newly acquired knowledge to the problem at hand. Their second focus is moving to a more general level of understanding, making transfer to new problems possible. After completing this problem-solving cycle, students will start to analyze a new problem, again following the analysis-research-report procedure.

Exhibit 2.1 contains an example of a first-year problem from the problem-based business program of the University of Limburg, Maastricht, the Netherlands. This problem is presented about three weeks after students have entered the business program. The problem is one in a series about how organizations should be structured and how they should formulate their organizational strategy given certain market demands.

Exhibit 2.1. Example of a First-Year Problem

For more than fifty years, the Lee Company of Merriam, Kansas, did a good steady business. In the 1960s and 1970s, Lee Riders were riding high as jeans became fashionable among women as well as men. Lee couldn’t make jeans fast enough. Recently, however, ten plants were closed down. Furthermore, Lee’s international sales decreased despite enormous demand in foreign countries. Nowadays, Chief Executive Officer Fred Rowan is struggling to reorient Lee to suit the changes in the external environment. In order to make a sound reorientation, what is the first thing Fred should do?
Analysis of this problem takes place through several stages. The first step students take is to make sure everybody understands all the concepts and terms used in the problem. Students can raise questions about the concepts of organizational environment, dynamics of market behavior, and market share. Depending on their prior knowledge, students ask for more information about certain concepts in the Lee Company problem. This step serves an important purpose in the learning process. As discussed in the previous section, Principle 1 says that learning new information is based on existing knowledge. The first step of clarifying concepts elicits and activates existing knowledge. The primary analysis of the problem serves to activate prior knowledge, allowing students to couple new information to existing knowledge. Consequently, as the tutor listens, he or she gets information about students' existing knowledge and their naive beliefs about the mechanisms underlying the problem.

During the next step, students define and analyze the problem. For example, in discussing the problem, students may question why in a stage of growing market demand, Lee Company is not able to sell jeans. At this point, students are confronted with conflicting information: there is a substantial market demand; in the past, Lee was more or less surfing on market demands because production could not keep pace with demand; and now market demand is still growing, but Lee is unprofitable. This problem increases their interest in knowing more about organizational behavior and market analysis, because the information in the problem conflicts with their naive beliefs about market demand and opportunities to sell products, which say that if market demand is large, Lee Company should not have these problems.

At this stage, Principle 2 gains importance. A tutor who understands the role well will not tell students whether they are right or wrong in their thinking. The tutor resists giving the "right" solution. In the perspective of teaching metacognitive skills, a tutor asks questions that monitor the progress of problem-solving action (a process discussed in Chapter One). This models the kind of questions that students should be asking to identify the nature of the problem and the kind of knowledge required to understand it. These questions also lead students from the concrete problem and toward conceptual knowledge. Another important tutor role is to teach students how they can take on the role of expert. That is, the tutor asks students to reflect upon their own problem-solving behavior, and emphasizes that acquiring knowledge is a means, not an end. Knowledge is instrumental in the pursuit of competence in effectively managing problems.

As a result of discussing the problem, students study the relationships between the environment of an organization and organizational behavior. Possible learning issues are: How does the environment of organizations influence organizational behavior? What kind of organizational strategies are most effective given certain market features? How do you conduct a marketing opportunity analysis to determine how a company can be restructured in response to market demands?
The PBL process is completed when students report in a subsequent group session about what they have learned. At this stage, Principle 3 is important. Learning occurred because students were motivated by issues raised during the initial discussion of the problem. They wanted to understand the problem. When students report on what they have learned, the tutor provides feedback regarding whether the original learning issues have been resolved and whether students understand the issues behind the problem in sufficient depth. That is, ultimately teachers are not concerned with the problem encountered by Lee Jeans Company, but by the general issue of how market environments influence organizational behavior. Given that contextualization of knowledge is important to facilitate the use of knowledge, attention needs to be paid to both the particular case of Lee Jeans Company and to the general issue of market environment and organizational behavior. The particular case provides the context for learning new information and serves as a stepping-stone for students to acquire knowledge about the general problem domain. In this final stage of problem-based learning, the tutor may also demonstrate how conceptual knowledge about market environment and organizational behavior can be used to analyze the organizational behavior of other companies in different market environments. This enables students to observe how knowledge from one problem may be transferred to new problem situations.

Opportunities to Improve Problem-Based Learning

Insights from cognitive theories may help us manipulate the features of problem-based learning to improve learning. Williams (1992) points out that PBL is a relatively new and different form of education. Consequently, implementing problem-based learning is a difficult process. It is even more difficult to get the most out of its potential. Two essential features of problem-based learning seem to have a large impact on students' learning: the role of the tutor and the format of the problems (Albanese and Mitchell, 1993).

Role of the Tutor. As described in previous sections, a problem serves as the initiator of or stimulus for the learning process. Activation of prior knowledge through small group discussion is a key variable in this process. The tutor has to find a balance between allowing students to discuss issues and intervening to make sure that the critical learning issues are raised (Williams, 1992, Wilkerson, 1995). Our experience at the University of Limburg shows that this is very difficult for teachers. Without this balance, a tutor may be overly passive or may intervene in such a way as to stifle student discussion, for example giving minilectures, asking a constant stream of questions, giving answers, or providing literature references. Passive tutor behavior violates the first two learning principles that stress active construction of understanding and the importance of metacognitive skills. Rigid intervening behavior shifts the focus of the problem-based tutorial away from student-centered learning and toward teaching, ignoring the principle that learning is a constructive and
not a receptive process. Recognizing that the tutor role is important, we need to include tutor development programs that stress how to realize active construction and metacognition.

**Format of Problems.** The second issue regards the format of problems. By this I do not mean the selection of problems, but the design of problems. Many different problem formats are in use in different programs. The design of effective problems is a painstaking process and few theory-based guidelines for problem construction are available in the literature (Schmidt, 1993; Gijsebaers, 1995). This makes it difficult to develop principles for effective problem design. However, this issue may also be approached by asking the opposite question, what features of problem design may reduce the potential of problem-based learning? The following paragraphs contain some examples of ineffective problem design, based on experiences at the University of Limburg:

- **Ineffective problem descriptions include questions that are substituted for student-generated learning issue.** Students use these questions as benchmarks that should be reached after problem analysis. The process of problem-solving action turns into a process of backward reasoning because students know in advance what the outcomes should be.

- **The title of an ineffective problem is similar to titles of textbook chapters.** Teachers use titles to lead students and ensure that course objectives are covered. This situation may occur when teachers are afraid that students will not study what was initially intended, if left to themselves.

- **An ineffective problem does not result in motivation for self-study.** A problem may not contain a conflict in need of clarification or the problem may be too simple and can be completely resolved during the initial analytic process. This situation occurs when problems look like end-of-chapter exercises, or have only one acceptable solution and strategy for reaching it. Such problems are well-defined instead of ill-structured (Bruning, Schraw, and Ronning, 1993). The result may be that students restrict themselves to checking whether everyone got the same solution.

There is a growing awareness that problems are central to effective problem-based learning. At the University of Limburg, several studies have been conducted focusing on the link between problem design, students' initial problem analysis, and student learning. Dolkens (1994) demonstrated that students are quite capable of identifying those learning issues that faculty expect them to learn. However, she also found that students use other signals such as literature references, content in previous tests, and information from lectures in their decision-making about what to study and how to study. Dolkens (1994) recommends more research into how these factors interact with features of problems, which might add to our understanding of principles for effective problem design.

**References**


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